# Search for Conical Emission with Three-Particle Correlations

**Claude A. Pruneau, for the STAR Collaboration**

Physics and Astronomy Department, Wayne State University, Detroit, MI 48152 USA

E-mail: `pruneau@physics.wayne.edu`



**Abstract.** We present preliminary STAR results on 3-particle azimuthal angle correlation studies in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The studies are carried out at mid-rapidity between a trigger particle with $3 \leq p_\perp \leq 4$ GeV/c and two associated particles in $1 \leq p_\perp \leq 2$ GeV/c. A cumulant analysis reveals finite 3-particle azimuthal correlations, dominated by near and away side particle correlations consistent with jet production, and jet-flow correlations. We use a two-component model to remove underlying background correlations. This analysis indicates the presence of the conical emission signals in central Au+Au collisions within the model assumptions about background composition and normalization.

## 1. Introduction

The observation of a dip at $180^o$ in flow subtracted two-particle azimuthal correlations observed in Au + Au collisions [1] was suggested as an indicator of the production of away-side parton induced wake field or Mach cone [2]. The dip might however also result from large angle gluon radiation [3], jets deflection by radial flow, or Cerenkov gluon radiation [4]. While discrimination of these production mechanisms is not possible with two-particle correlations, it might be achieved with three particle correlations.

We present the results of **two** parallel approaches, by STAR, to search for conical emission in Au + Au collisions at $\sqrt{s_{NN}}$=200 GeV using three particle cumulants [7] and a two-component model based subtraction method [8].

The analyses use Au+Au datasets consisting of nearly 20 million minimum bias and 22 million central-trigger collected during RHIC run 4. Correlations are measured between three charged particles in the range $|\eta| < 1$ in terms of two relative azimuthal angles $\Delta\varphi_{ta}$ and $\Delta\varphi_{tb}$. Particle "t", selected in the range $3 \leq p_\perp \leq 4$GeV/c, serves as a jet tag or trigger while particles "a" and "b", in the range $1 \leq p_\perp \leq 2$GeV/c, probe the jet structure and presence of conical emission. Mach cone emission shall lead to jacobian peaks at $\Delta\varphi_{ta} = \pi \pm \theta_M$, $\Delta\varphi_{tb} = \pi \pm \theta_M$, with the Mach angle $\theta_M$ determined by the sound velocity in the produced medium.

Preliminary three particle analyses were presented at QM05 [5], and elsewhere.

## 2. Three-Particle Cumulant Analysis

The 3-cumulant, introduced in [7] and also discussed in [9] is defined as

$$C_3(\Delta\varphi_{(ta)}, \Delta\varphi_{(tb)}) = \rho_3 - \rho_2^{(ta)}\rho_1^{(b)} - \rho_2^{(tb)}\rho_1^{(a)} - \rho_2^{(ab)}\rho_1^{(t)} + 2\rho_1\rho_1\rho_1 \qquad (1)$$

in terms of the measured 3-particle density (number of triplets/event) $\rho_3 \equiv dN/d\Delta\varphi_{ta}d\Delta\varphi_{tb}$ and combinatorial terms $\rho_2^{(ij)}\rho_1^{(k)}$ and $\rho_1\rho_1\rho_1$ calculated based on measured 2- and 1- particle densities. Figure 1 presents the 3-cumulants measured in three ranges of centrality. The 3-cumulants feature prominent peaks at (0,0), ($\pi$,$\pi$), (0,$\pi$), and ($\pi$,0). One also notes the presence of weaker peaks positioned at regular intervals. These are strongest in 10-30% collisions where $v_2$ and $v_4$ flow coefficients are the largest, and are qualitatively understood as arising from irreducible non-diagonal collective flow contributions of order $v_2v_2v_4$ [7]. Calculation of these contributions based on parameterizations of measured $v_2$ and $v_4$ [10] yield amplitudes compatible with those observed in Fig. 1. The near- and away-side structures are present at all centralities, i.e. even for the most central collisions. While their presence can in part result from jet emission alone (with two associated particles either on the near or away-side), they may also result from the interplay of jet correlations with the event reaction plane and particle flow. Their interpretation thus require further work. Note finally the away-side structures are inconsistent with global momentum conservation effects expected to produce broad structures in three-particle correlations [6].

Next examine the 3-cumulant and their projections (bottom part of Fig 1.) to seek evidence of structures produced by conical emission [7] along the diagonals 60-80$^o$ from the away-side direction. Projections axes are set to show away-side peak at 0 radian. The projections exhibit structures consistent with $v_2v_2v_4$ terms but no clear evidence for conical emission. It is however conceivable that conical emission is masked by flow terms, or simply too weak to be visible in this analysis.

## 3. Two component Subtraction Method

Preliminary results obtained with this analysis technique described in [8] were already reported [5, 11]. Current results are also presented in QM06 poster proceedings [12]. This method is based on a measurement of three-particle density normalized per trigger particle. It includes explicit removal of $v_2^2$, $v_4^2$, $v_2v_2v_4$ terms, and carries combinatorial term subtraction using a zero yield at 1 radian (ZYA1) hypothesis [8]. Fig. 2 presents the correlations obtained after flow and combinatorial subtraction for $d + Au$, and selected $Au+Au$ centralities. The correlation obtained for 80-50% $Au+Au$ collisions is qualitatively similar in shape to that obtained in $d+Au$ as well as that measured with the cumulant method. At 12-0% centralities, the shape of the away-side structure is however substantially modified relative to the peripheral bin: two broad peaks are observed along the main diagonals at angles of $\pi \pm 1.45$ rad. One also observes off diagonal structures at ($\pi \pm 1.45$, $\pi \mp 1.45$). Diagonal projections shown in Fig. 2 (bottom) indicate these structures are statistically significant, and thus suggest evidence for conical emission

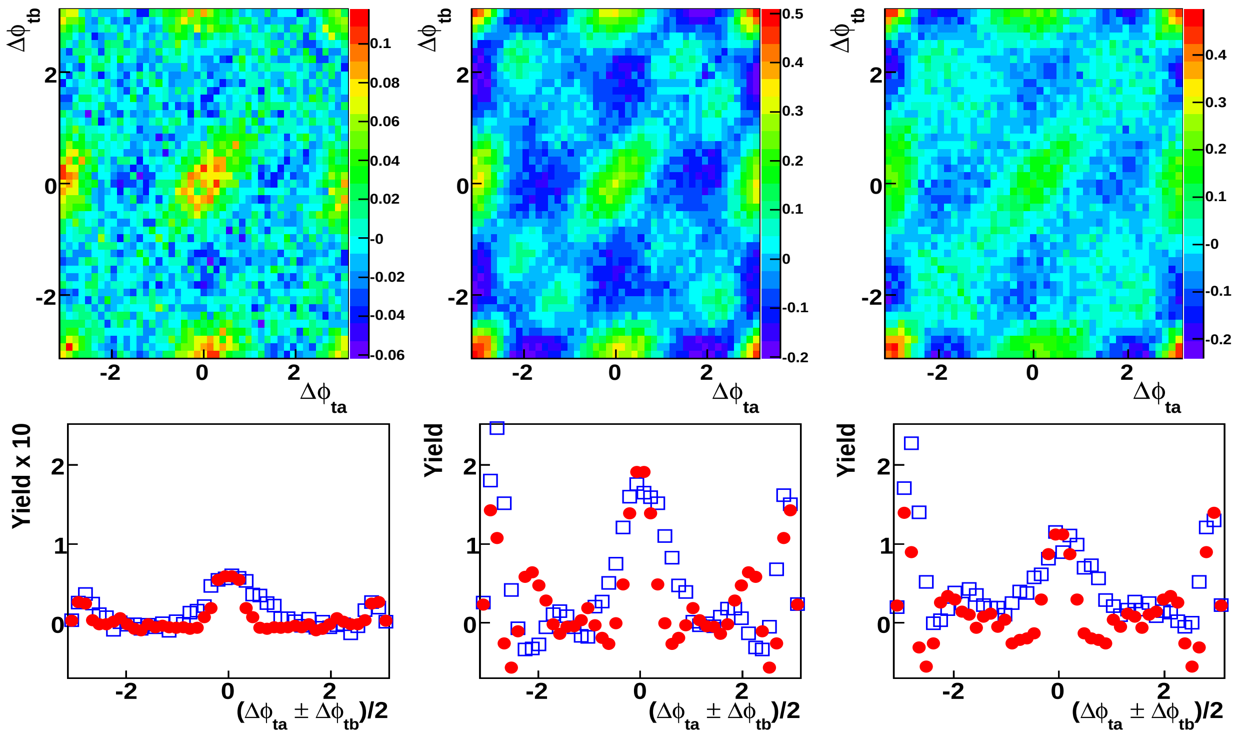


**Figure 1.** 3-cumulants for (left) 80-50% (scaled x 10) (center) 30-10% and (right) 10-0%, and projections along the main (blue open squares) and alternate diagonals (red circles). Solid and dash lines at $\pi$ and $\pi\pm$ 1.2 respectively. ALL RESULTS PRELIMINARY.

in the most central bin shown, although the amplitude of the structures depends on the inclusion of a flow-jet correlation component, the amplitude of the $v_2$ and $v_4$ flow, and combinatorial terms normalization. Systematic effects associated with variation of $v_2$ and $v_4$ are shown as (yellow) histogram band in Fig 2. The position of the peaks angles, at $\pi \pm -1.45$, if arising from Mach cone emission, would suggest the sound velocity is rather modest in the produced medium [2]. Further work is in progress to fully understand these effects.

## 4. Summary

We presented preliminary results from two on-going STAR searches for conical emission in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The cumulant analysis reveals finite three particle correlations dominated by near and away side particle correlations consistent with jet production. No clear evidence for conical emission is observed with this method, but the signal may be masked by the presence of irreducible flow components [7]. The model-based subtraction method yields similar results for peripheral collisions, but reveals structures at ($\pi \pm 1.45$, $\pi \mp 1.45$) suggestive of conical emission in more central collisions. Further work is in progress to understand the methods sensitivity, systematic effects, and overall robustness of these results.

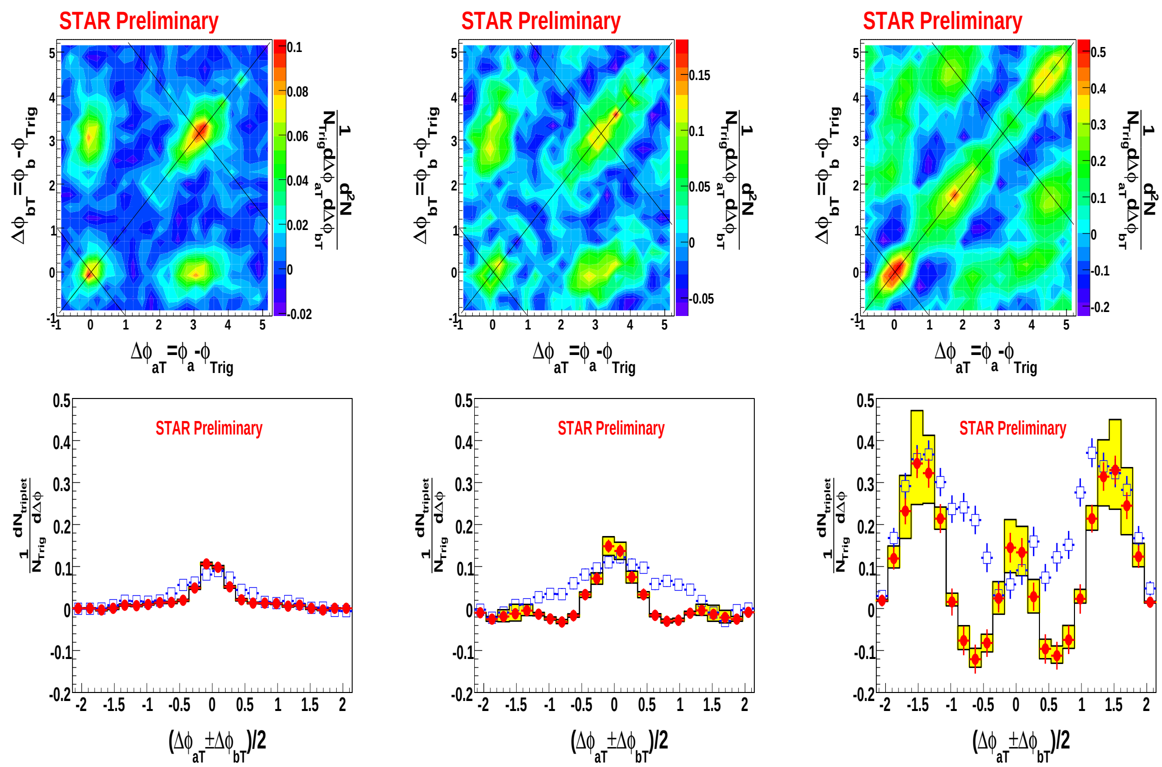


**Figure 2.** Correlations obtained with model-based subtraction for (left) d+Au, (center) 80-50% Au+Au, and (right) 12-0% Au+Au collision. The bottom plots show projections along the main (blue) and alternate (red) diagonals.

**Acknowledgments** This work was supported, in part, by U.S. DOE Grant No. DE-FG02-92ER40713.

## References

[1] J. Adams *et al.* (STAR Collaboration), Phys. Rev. Lett. **95**, 152301 (2005).
[2] H. Stoecker, Nucl. Phys. **A750**, 121 (2005); J. Casalderrey-Solana *et al.* J. Phys. Conf. Ser. **27**, 23 (2005).
[3] I. Vitev, Phys. Lett. B **630**, 78 (2005).
[4] I.M. Dremin, Nucl. Phys. A **767**, 233 (2006); V. Koch, A. Majumber, X.-N. Wang, Phys. Rev. Lett. **96**, 172303 (2006).
[5] J. Ulery, *et al.* (STAR Collaboration), Nucl. Phys. A **774**, 581 (2006).
[6] N. Borghini, nucl-th/0612093.
[7] C. Pruneau, Phys. Rev. C **74**, 064910 (2006).
[8] J. Ulery and F. Wang, nucl-ex/0609016.
[9] C. Pruneau, QM06 Poster Proc. to appear in Int. Jour. Mod. Phys. E.
[10] Y. Bai, *et al.* (STAR Collaboration), QM06 Poster Proc. to appear in Jour. Phys. G.
[11] J. Ulery *et al.* (STAR Collaboration), Hard Probes Conf. Proc. 2006, Pacific Grove, CA, USA, nucl-ex/0609047.
[12] J. Ulery *et al.* (STAR Collaboration), QM06 Poster Proc. to appear in Int. Jour. Mod. Phys. E.